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EFFECTS OF AMBIENT AIR QUALITY ON CHILDREN'S LUNG FUNCTION IN URBAN AND RURAL IRAN

Maryam Mandana Asgari

Yale University

1997

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EFFECTS OF AMBIENT AIR QUALITY ON CHILDREN'S LUNG FUNCTION IN URBAN AND RURAL IRAN

A Thesis Submitted to the
Yale University School of Medicine
in Partial Fulfillment of the Requirements for the
Degree of Doctor of Medicine

by

Maryam Mandana Asgari

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ABSTRACT

EFFECTS OF AMBIENT AIR QUALITY ON CHILDREN'S LUNG FUNCTION IN URBAN AND RURAL IRAN.

Maryam M. Asgari. (Sponsored by William S. Beckett). Yale University School of Medicine, New Haven, CT.

A cross-sectional epidemiological study comparing the pulmonary function of children in Tehran with those in a rural town in Iran was conducted in the summer of 1994. Four hundred children ages 5-11 were studied. Daytime ambient NO_2, SO_2, and PM_{10} were measured by portable devices in the children's neighborhoods on the days they were studied. Levels of these ambient substances were markedly higher in urban Tehran. Children's parents were questioned about home environmental exposures (including heating source and environmental tobacco smoke) and children's respiratory symptoms. Pulmonary function was assessed both by spirometry and peak expiratory flow meter. FEV_1 and FVC as a percent of predicted for age, sex and height were significantly lower for urban children compared with rural children. Both measures showed significant associations with levels of SO_2, NO_2 and PM_{10}. Differences in spirometric lung function were not explained by nutritional status as assessed by height and weight for age, nor by home environmental exposures. Reported airway symptoms (cough, phlegm, and wheeze) were higher among rural children, while reported physician diagnosis of bronchitis and asthma were higher among urban children. This association of higher pollutant concentration with lower pulmonary function in this urban rural comparison suggests an effect of urban air pollution on short-term lung function and/or lung growth and development during the pre-adolescent years.

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INTRODUCTION

As the population of developing nations continues to increase at an alarming rate, so does their consumption of energy. The majority of the energy for industry, domestic use and transport is provided by fossil fuel combustion. Combustion of fossil fuels releases a variety of pollutants into the atmosphere, including sulfur oxides (SO_2 and SO_3), nitrous oxides (NO_2 and NO_3), ozone (O_3), carbon monoxide (CO) and particulate matter (PM). These pollutants can accumulate to reach toxic levels in cities within developing nations with rapid rates of industrialization and population growth. For Tehran, one of the world's megacities with the eighth highest population[1], air quality has been especially problematic. Within the past decade, the levels of major air pollutants have exceeded three to four fold the internationally adopted World Health Organization standards.[2]

FACTORS INFLUENCING TEHRAN'S AIR QUALITY

Levels of air pollutants are determined by a balance between the types and quantities of pollutants produced by various sources and the amount cleared by winds and precipitation. As Iran's capital city, Tehran is the financial, commercial and industrial center of the country. The principal sources of air pollution, namely heavy industry and motor vehicle traffic, are concentrated within the city's boundaries. Within the past twenty years, the city's

population has grown at a tremendous rate leading to further increases in industrial and motor vehicle activity. Tehran's geographic location, however, is such that dispersion of pollutants via strong winds and precipitation occurs infrequently. This imbalance of production versus clearance of air pollutants has lead to Tehran's current poor air quality.

Cleansing Sources: Geographic Location and Meteorologic Factors

Tehran is located 1,200 meters above sea level in northern Iran on a plain south of the Alborz mountains (Figure 1). With an average annual precipitation between 200 to 1400 mm/year, Tehran's climate is arid. The "rainy season" encompasses three months starting in late fall and ending in early spring. The precipitation, being brief in both duration and quantity, is insufficient to cleanse the air of pollutant gases and precipitate suspended particles which are emitted on a year-round basis.

Another climatic variable that influences concentration of pollutants is wind-speed and direction. The Alborz mountains north of Tehran set up wind patterns dominated by winds that travel from mountain to plain and plain to mountain. These winds can be categorized into two types based on their speed: strong (> 17 knots) and weak (<17 knots). The strong winds, which are capable of blowing the polluted air over and beyond the city boundaries, occur very rarely and comprise approximately 5% of the total winds.[3] The weak

winds merely function to sweep the polluted air back and forth between the north and south end of the city. The lack of strong winds prevents dispersion and dilution of air pollutants.

Not only is horizontal circulation of air limited by lack of strong winds, but frequent temperature inversions prevent vertical air circulation. Under normal conditions, pollutants emitted from combustion processes are hotter than ambient air. Upon contact with the cooler ambient air, the gaseous pollutants rise. During temperature inversions, however, masses of cold air get trapped underneath warm air. Within the cold air mass, temperature paradoxically increases with altitude as the cold air rises to meet the warm air mass above it. This so called "inversion layer" traps pollutants close to the emission source. Thus, air pollution tends to accumulate waiting to be dispersed by an alternate airflow pattern or by strong winds.

The combination of frequent inversions, weak winds, and scarce precipitation which result from Tehran's unique geographical location thus contribute to the poor air quality within the city.

Pollutant Sources: Heavy Industry and Motor Vehicles

The livelihood of most urban centers depends upon the production and consumption of energy. Energy is required for industrial processes, motorized transport, as well as domestic activities such as heating and cooking. In

developing nations, fossil fuels provide the principal source of energy. Iran, having access to one of the world's richest oil reserves in the Persian Gulf, relies on crude oil as a source of energy. As the most industrialized urban center in Iran, Tehran is responsible for over 50% of the country's total oil consumption. The city harbors thirty seven percent of the nation's industrial activity including oil refineries, cement plants, sulfuric acid plants, plaster works and foundries.[4] These industries lack stringent emission standards.

Industrial processes are not, however, the main culprit of the air pollution problem in most urban centers. That distinction goes to motor vehicles. According to Zerbonia et al.,[4] motor vehicles account for between 60 and 90 percent of most air pollutants in Tehran. A recent report documented that 7.5 million liters of gas are consumed on a daily basis by automobiles within the city. The automobiles disperse a combined annual total of 3,000 tons of CO, 120 tons of nitrogen dioxide, 30 tons of sulfur dioxide, and 30 tons of particulates into the air.[5] The amount of pollution is determined by the sheer number of vehicles on the road at any given time (estimated at about 2 million)[2], but also with the year and make of the vehicle. Old vehicles tend to be less fuel efficient and have poorer emission controls. They also tend to be more poorly maintained. In Tehran, however, automobiles are a near necessity due to the lack of an effective means of public transportation within the city.

Deterioration of the air quality in Tehran over the past few decades is primarily due to increasing industrial productivity and motor vehicle traffic in response to a several-fold rise in population. Iran has one of the highest population growth rates of any country in the world. From 1980 to 1990, the city's population increased by 40% from approximately 5.55 million to 9.21 million. The rate of growth is anticipated to continue, resulting in an estimated population of 13.78 million by the year 2000.[1] The growing urban population has led to increasing energy consumption, and hence, more emissions.

The resulting population boom has also led to unrestricted urban sprawl. Since 1956, Tehran, which used to encompass an area of approximately 80 km^2, has expanded to cover over 600 km^2. The average distance traversed to get from one point to another within the city has increased. On any given day, it is estimated that 10,000,000 trips are made, each lasting 45 minutes and covering a distance of 60 km. [2] Such heavy motor vehicle usage results in more emissions.

The fast-paced urban spread did not allow for implementation of strict planning on housing or industry to address overcrowding. Poor urban planning meant that new residential communities could spring up in close proximity to stationary sources of air pollution. It also lead to a dearth of

protected areas such as parks and open green spaces. Thus more people were at risk for exposure to the increasingly polluted air.

In summary, rapid expansion, urbanization and overpopulation, combined with the unique features of the geographic location of Tehran have lead to the high air pollution levels seen today. The major sources of pollutants within the city are motor vehicles with contributions from heavy industry.

AIR QUALITY: WHAT IS BEING MEASURED AND WHY

Recognition of an association between ambient air quality and respiratory health dates back to the 14th century when coal was first explored as a fuel source.[6] However, it wasn't until several centuries later that the adverse health effects of air pollution were brought to public attention. Between the 1930s to the 1950s, several air pollution catastrophes brought about increases in mortality among inhabitants of heavily industrialized areas. Among the most notable were epidemics in the Meuse Valley of Belgium in 1930, Donora, Pennsylvania in 1948 and London in 1952. These epidemics, the worst of which occurred in London and resulted in an excess mortality greater than 4,000 people, focused international attention of the scientific and legal communities on air quality.[7]

In response to growing concern about the adverse effects of air pollution, the World Health Organization set out in 1972 to establish international

guidelines outlining the amount and the duration of exposure to various air pollutants at which no adverse health effects would be expected to occur (WHO, 1976). The resulting WHO guidelines, which were last revised in 1987, are now the most widely used international guidelines.

In the United States, the guideline of choice is the National Ambient Air Quality Standards (NAAQS) established buy the Environmental Protection Agency (EPA). The NAAQS provide criteria for six pollutants identified by the 1990 Amendment of the Clean Air Act including nitrogen dioxide, sulfur dioxide, respirable particulate matter, carbon monoxide, ozone and lead. Assessment of air quality involves the comparison of levels of air pollutants against these established guidelines.

The health effects of inhaling air pollutants have been extensively studied, both experimentally and epidemiologically. In experimental studies, many of these pollutants have been correlated with adverse changes in pulmonary function. Three of these pollutants, nitrogen dioxide, sulfur dioxide and respirable particulate matter, will be the focus of this study.

Nitrogen Dioxide

Sources

Nitrogen dioxide forms in the process of high temperature combustion, where oxygen (O_2) combines with nitrogen (N_2) to make nitrogen oxide (NO),

nitrogen dioxide (NO_2) and other nitrogen oxides (NO_x). NO_2 can react with aerosols to form nitrous and nitric acids or alternatively, react with oxygen and hydrocarbons in sunlight to form ozone and other photochemical oxidants. The primary source of nitrogen dioxide in urban air is motor vehicle emissions. Other contributors include fossil fuel burning industries as well as chemical and nitration industries.

The National Ambient Air Quality Standard (NAAQS) recommends an annual arithmetic mean of NO_2 less than 0.053 ppm as a guideline (Table 2). The concentration of NO_2 in most urban centers world-wide ranges from an annual mean of 0.01 to 0.06 ppm.[8] The range reflects differences in fossil-fuel consumption. Within cities, ambient levels vary with traffic density. During rush hour traffic, there is a corresponding peak in NO_2 emissions. Heavily trafficked roads can average hourly concentrations of NO_2 as high as 0.5 ppm.[8] These levels far exceed the WHO guideline of 0.21 ppm as the recommended one-hour maximum level (Table 2).

Unlike other ambient air pollutants, NO_2 can occur in high concentrations indoors as well as outdoors. In homes containing sources of NO_2 such as unvented gas appliances and oil stoves, the concentration of NO_2 indoors can often exceed the outdoor concentration.[9] For example, during cooking, maximum hourly concentrations of indoor NO_2 can reach levels as high as 1.0

ppm.[8]

Kinetics and Toxicity

Due to its low water solubility, NO_2 has the capacity to penetrate into the lower airways, where more than 60% is deposited.[10] The pattern of deposition is predominantly centri-acinar. During normal breathing, the nasopharynx prohibits a significant portion of NO_2 from reaching the lower airways. However, during exercise when breathing is shifted through the mouth, a greater amount of NO_2 reaches the lung periphery. Bauer et al.[11] conducted a study where they noted a 17% increase in the deposition of NO_2 with exercise, suggesting that exposure during exercise may potentiate NO_2's adverse health effects. NO_2 is thought to produce adverse pulmonary health effects through oxidative capacities.

Alterations in Pulmonary Structure

Animal studies have shown that pulmonary epithelium can undergo irreversible morphologic changes after prolonged NO_2 exposure including hypoplasia of terminal bronchi as well as shortening and decrease in number of cilia.[12] Type I pneumocytes and ciliated epithelium, which are most sensitive to NO_2 exposure, are often replaced by less sensitive Type II cells. Cytoarchitectural changes can also be induced in these substitute cells after acute exposures to NO_2 levels above 0.5 ppm.[13] Emphysema-like changes, such

as loss of alveolar structure and enlargement of air-spaces, were noted in the lungs of animals that were exposed to high levels of NO_2 (20 ppm for 30 days).[14] The mechanism by which chronic high-dose NO_2 exposure leads to these structural changes is thought to be mediated by inactivation of lung protease inhibitors. In a study conducted on human subjects, bronchoalveolar lavage fluid demonstrated a 45% decrease in activity of the alpha-1 protease inhibitor after exposure to 3 or 4 ppm NO_2 for 3 hours.[15] Deficiency in lung proteases has been linked with the occurrence of emphysema in humans.

Alterations in Pulmonary Function

Controlled human studies have failed to show significant changes in the pulmonary function of normal subjects in response to acute NO_2 exposures. Exposures of 2.0 to 4.0 ppm NO_2 for periods of time ranging from 75 minutes to three hours have not shown decrements in pulmonary function as measured by spirometry or flow resistance.[16-17] Although pulmonary function does not appear to be directly affected, bronchial reactivity, as measured by bronchoconstriciting agents, does increase with acute NO_2 exposures at levels as low as 1.5-2.0 ppm for 3 hours.[17-18]

Asthmatics may be more sensitive to NO_2. The data on asthmatic subjects is controversial. Bauer et al, 1986 [11] studied 15 asthmatics who were exposed to 0.3 ppm NO_2 for 30 min (20 minutes of rest followed by 10 minutes of

exercise), after exercise, noted a significant reduction in forced expiratory volume in one second. Morrow and Utell were unable to confirm the decrement in lung function in a study of 20 asthmatics exposed to the same level of pollutant for 4 hours.[19] No pulmonary function changes were found for asthmatics exposed to 0.15 to 0.6 ppm NO_2 for 75 minutes,[20] 0.2 ppm for 2 hours,[21] or 0.3-0.4 ppm for 75 minutes.[22] The inconsistency of these results may be attributable to differing experimental protocols such as exercising vs. non-exercising or subject selection, such as mild vs. severe asthmatics.

Effects on Respiratory Symptoms

Epidemiologic studies suggest that a positive correlation exists between respiratory symptoms and levels of NO_2 exposure. In the Harvard Six Cities study, respiratory symptoms including shortness of breath with wheeze, chronic wheeze, chronic cough, phlegm, and bronchitis increased in prevalence with increasing indoor NO_2 concentrations.[23] Melia et al. also noted an association between living room NO_2 levels and respiratory symptoms.[24] With regard to the effects of ambient NO_2 on respiratory symptoms, several studies in Chattanooga, Tennessee have revealed an association with respiratory illness, especially amongst children. Chattanooga is home to a munitions factory which emits NO_2 into surrounding areas. Residents who are in close proximity to the factory are exposed to higher levels of ambient NO_2 than

those who reside further away. However, both communities are exposed to similar levels of SO_2 and particulate matter. Comparison of the rates of respiratory illness amongst the two communities has shown that the rates of respiratory illness are higher among families, and bronchitis episodes higher among school children in the high-exposure area.[25-26] Meta-analysis of the epidemiological studies shows that an long-term increase in exposure to NO_2 of 0.015 ppm is associated with an increase odds of respiratory illness of approximately 20% in children.[10]

The increase in respiratory symptoms may be due, in part, to increasing susceptibility to bacterial and viral lung infections. Animal studies suggest that exposure to NO_2 at levels approximately an order of magnitude above ambient levels impairs immune responses to some bacteria and viruses. The experimental protocol employed in the majority of these studies involved exposure to NO_2 followed by inhalation of a pathogenic organism. These studies detected increased mortality from a bacterial challenge following NO_2 exposure.[27] With respect to viruses, Henry et al.[28] showed that prolonged exposure to 1.0 ppm NO_2 in squirrel monkeys was associated with enhanced serologic evidence of influenza virus. In mice, intermittent exposure to 5 ppm for 6 days decreased by nearly 100-fold the amount of viral innoculum needed to induce infection.[29]

Alveolar macrophages appear to be the target for NO_2's immune effects. In a study of brochoalveolar lavage fluid derived from human lungs after exposure to 2.0 ppm NO_2 for 4 hours, alveolar macrophages displayed impaired phagocytic activity and decreased superoxide anion production.[30] The macrophage's capacity to defend against pathogens in vitro also appears to be diminished with NO_2 exposure. After 3 hours of exposure to 0.60 ppm NO_2, alveolar macrophages obtained by brochoalveolar lavage from human subjects inactivated influenza virus less effectively than macrophages obtained after exposure to air.[31] These studies suggest that NO_2 has a detrimental effect on the ability of alveolar macrophages to perform their immune function.

Sulfur Dioxide

Sources

Sulfur dioxide (SO_2) is a clear, highly soluble gas that originates from the burning of sulfur containing compounds such as coal and crude oil. Sulfur dioxide may be further oxidized in the atmosphere to sulfur trioxide which can be converted to sulfuric acid in the presence of moisture. SO_2 can also react with metals and other pollutants to produce metallic acids and ammonium sulfates.

Major industrial sources of SO_2 include electrical power plants, oil refineries and smelters. The concentration of SO_2 in urban centers world-wide

ranges from an annual mean of 0.035 to 0.070 ppm,[8] reflecting differences in fossil-fuel consumption. Peak hourly concentrations of SO_2 can rise as high as 0.35 to 0.70 ppm. Indoor concentration of SO_2 tends to be low as a result of absorption of the gas by walls, furniture and fabric.

Kinetics and Toxicity

Due to its high water solubility, SO_2 is effectively absorbed by mucous membranes lining the upper respiratory airways under resting conditions. With increased mouth ventilation, more SO_2 penetrates into the deeper portion of the lungs. SO_2 interacts with the mucus layer of the upper airways resulting in the production of hydrogen ions, bisulfate, and sulfate ions, all three of which have the potential for local irritation. These molecules are thought to cause brochoconstriction by acting on sensory afferent nerve fibers in pulmonary smooth muscle.[32]

Alterations in Pulmonary Structure

At high concentrations (>300 ppm), animal studies have shown that SO_2 can potentiate bronchitis-like pathology with sloughing of ciliated epithelium in the trachea and proximal airways and subsequent replacement by secretory cells.[33] Mice exposed for 72 hours to 10 ppm SO_2 had subsequent edema, necrosis and desquamation of their respiratory and olfactory epithelium in mice.[34] At ambient SO_2 levels, however, animal studies fail to indicate acute or

chronic toxicity.

In human subjects, ciliary abnormalities were discovered in the nasal epithelia cells after a two hour exposure to 0.75 ppm SO_2.[35] Altered mucociliary clearance is postulated to underlie the reduction in tracheobronchial clearance rate after exposure to acid sulfates. The suppressive action of the acid aerosol increases with rising acidity and appears to be cumulative.[36]

Alterations in Pulmonary Function

Experimental studies on healthy humans have failed to demonstrate an acute effect of SO_2 on pulmonary function at levels which typically occur during air pollution episodes.[37-39] Asthmatics, however, are sensitive to even low levels of SO_2. Exercising asthmatics can experience bronchoconstriction at concentrations of 0.25 ppm SO_2.[40-41] Asthmatic subjects exposed to 0.25 ppm SO_2 for brief periods lasting 5-10 minutes can develop significant increases in airway resistance, and decreases in FEV_1, especially with oral breathing.[42] Although these changes in pulmonary function are rapid and remain stable with lengthening exposure, they are readily reversible and resolve within an hour after the end of exposure.

Effects on Respiratory Symptoms

In epidemiological studies, exposure to levels of SO_2 as low as 0.5 ppm has

been shown to increase mortality.[8] One such study, which followed 5,500 women in western Pennsylvania, noted an increased frequency of respiratory symptoms associated with levels of ambient SO_2.[43] Euler et al.[44] studied Seventh-Day Adventists in California and found that their incidence of respiratory symptoms such as chronic cough/phlegm, diagnosis of asthma with wheeze or emphysema was associated with cumulative SO_2 and particulate exposures. The strongest association was found with particulates. SO_2 and particulates often occur together as components of a complex mixture of emissions from primary combustion. Increasing epidemiological evidence points to particulates as being the more toxic of the mix.

Particulate Matter

Sources

Particulate matter is produced by incomplete combustion of fossil fuels. Inefficient combustion of carbon containing fuels releases a mixture of solid and liquid particles that are collectively termed total suspended particles (TSP). Constituent particles vary in size and composition and include carbon, lead, vanadium, bromine, sulfur oxides, nitrogen oxides, silicon, aluminum, iron, sodium and chloride. The concentration and composition of particulate air pollution varies with the source, the dispersion by air motion, and the amount of time available for sedimentation. There is a wide range of

concentrations of particulate matter throughout urban centers of the world. In developing countries, the particulate levels can range as high as 100 times the current U.S. standards.[7]

Kinetics and Toxicity

The toxicity of particulates varies with the size and the physical composition of the mixture. Particulates can be classified on the basis of their size. Particles greater than 10 microns in diameter tend to be deposited above the epiglottis, adhering to nasal hairs and mucous membrane of the nose. Particles up to 10 microns in diameter (PM_{10}), otherwise referred to as respirable particles, tend to be deposited in the upper and lower airways. Particles less that 5 microns in diameter (PM_5) can be inhaled and can penetrate to the alveoli. Exercise increases oral breathing and therefore bypasses the nasal clearance mechanism. Consequently, the deposition pattern changes with more particulates being deposited in the lower airways.

Particle clearance depends on the site of deposition. Particles deposited in the anterior nasal cavity are cleared by sneezing or wiping whereas those in the posterior cavity are cleared to the posterior pharynx and swallowed. Particles in the trachea, bronchi and bronchioles are moved up the tracheobronchial tree by the sweeping action of the cilia to be expelled by coughing or swallowing. In the terminal bronchioles and alveoli, particles are cleared by lung

macrophages. Fine particles < 5 microns in diameter may pass through the alveolar tissue and move into the lymphatic circulation.

The chemical composition and kinetics of many of the components of particulate matter has not been fully elucidated. Toxicologic studies have focused primarily on the effects of single components of particulate matter or on simple mixtures. Yet many of the toxic effects of particulates are thought to derive from the combination of the complex mixtures which includes SO_x as well as acid aerosols. The lack of standardization of dosimetry for different particulates in complex mixtures makes for comparison of most toxicologic studies difficult. In preliminary studies, particulate complexes appear to be far more toxic to macrophage defense capabilities than classic particles such as asbestos and silica.[45]

Alterations in Pulmonary Structure

In animal studies, edema and pathologic changes were noted to occur in animals within 24 hours of exposure to particulates from space heaters, burning wood, coal, and automotive waste oil.[46]

Alterations in Pulmonary Function

Numerous studies have documented an association between particulate pollution and decreased pulmonary function both in healthy volunteers as well as those with preexisting respiratory conditions. In a study of 335 healthy

children, a decrease in $FEV_{0.75}$ and FVC was noted after an air pollution episode where the concentration of TSP reached a 24 average of 312 μg/m^3.[47] Dassen et al.[48] reported a decrement in FEV_1 and FVC in children in Ijmond, Netherlands associated with TSP levels of 200-250 μg/m^3. Focusing on a population more prone to respiratory illness, Pope and Kanner [49] found that in over 6,000 cigarette smokers, changes in FEV_1 and FEV_1/FVC were inversely associated with changes in levels of PM_{10}. They noted that a 100 μg/m^3 increase in PM_{10} levels resulted in a 2% drop in FEV_1.

Effects on Respiratory Symptoms

Epidemiologic studies indicate a link between particulate air pollution and increased respiratory morbidity and mortality. One study of patient records in Ontario indicated a marked association between admissions for acute respiratory disease and levels of SO_2 and floating particulate matter.[50] Pope demonstrated a statistical association between respiratory hospital admissions and particulate matter in Utah, Salt Lake, and Cache valleys.[51] In a health interview survey of 50,000 households over a five year period, Ostro et al.[52] found an association between fine particulate matter and respiratory conditions severe enough to result in work loss and disability in adults. Total number of emergency room visits were associated with ambient levels of TSP in Steubenville, Ohio.[53] In a multiple regression analysis, an overall increase of

100 $\mu g/m^3$ over the base-line 24 hour mean PM_{10} increased emergency room visits for respiratory disease by 3%.[54]

Particulates have been singled out as the major cause of mortality in the 1952 epidemic in London.[55] More recently, Schwartz and Dockery [56] associated daily mortality counts for a seven year period in Philadelphia with daily concentration of particulates. In examining the mortality data, they found significant correlation with daily mortality counts of death and particulate and SO_2 concentrations for the current and preceding day. Controlling for season, temperature and humidity, total mortality increased by 7% per 100 $\mu g/m^3$ increase in total suspended particulates. Mortality data from Steubenville, Ohio also showed a significant association between daily total mortality and TSP concentration on the previous day.

In a review of the epidemiologic literature, Dockery and Pope [57] concluded that for each 10 $\mu g/m^3$ rise in levels of PM_{10}, there is a corresponding 1% increase in total mortality, a 1.4% increase in cardiovascular mortality and a 3.4% increase in respiratory mortality. With regard to morbidity, there was a corresponding rise of 1% in the incidence of all respiratory symptoms requiring medical attention with 2-3% increase in asthma alone. By demonstating quantitively similar adverse effects of acute PM_{10} exposure, these results suggested coherence across morbidity and mortality data.

AIR QUALITY STUDIES IN TEHRAN

In Tehran, the effects of air quality on respiratory morbidity were examined by Shamsi[2] who studied 10,720 children in 3 different areas of Tehran. He selected the relatively unpolluted area in northern Tehran (Area 1), and two highly polluted areas in City Center (Area 2) and southern Tehran (Area 3). He measured SO_2 and TSP in these areas and found annual mean concentration (in $\mu g/m^3$) of $SO_2=53.06$ and $TSP=12.5$ in Area 1, $SO_2=198.48$ and $TSP=442.28$ in Area 2, and $SO_2=227.04$ and $TSP=309.08$ in Area 3. He administered a questionnaire examining respiratory symptoms and found that the percentages of children with asthma and bronchitis in Areas 1, 2, and 3 were 1.9, 5.6, and 4.4 respectively. TSP appeared to be a stronger factor in predicting respiratory symptoms among children living in Tehran.

STATEMENT OF PURPOSE

The goal of this project was to assess how levels of air pollutants, namely SO_2, NO_2 and PM_{10}, affect pulmonary function and respiratory symptoms of children in Tehran. Children were chosen as the subjects of the study because according to statistics of the Department of Public Health in Tehran, the rate of respiratory disease is high and the majority of the city's patients consist of children.[2] Children's lungs may be more vulnerable to the effects of air

pollution. To assess the degree to which lung function of the indigenous population of Tehran is altered as a result of exposure to high levels of air pollutants, the lung functions of children in Tehran were compared to those of an unpolluted nearby rural area.

Lung function measurements consisted of peak expiratory flow readings (PEF) and spirometeric tracings of forced expiratory volume at one second (FEV_1) and forced vital capacity (FVC). PEF, FEV_1 and FVC for the two sites were compared and subsequently correlated with levels of air pollution as measured by portable air quality monitoring devices. To assess respiratory symptomatology as well as the contribution of possible confounding variables, the parents or guardians of each subject completed a detailed questionnaire at the time of testing regarding parameters such as indoor air quality, parental smoking patterns, socioeconomic status and nutrition.

METHODS

The study was conducted from June to August of 1994. The summer months were chosen to minimize the incidence of upper respiratory infections which could potentially confound the results of pulmonary function studies.

STUDY SITES

The study sites were selected to represent areas of high and low exposure to

SO_2, NO_2 and particulate matter. The highly polluted district of Neeknejad in the inner city of Tehran (henceforth designated “urban”) was chosen because of its proximity to mobile sources of air pollution such as heavily congested throughways and railroads as well as stationary sources such as a nearby cement factory. The district of Lavasan (“rural”), located approximately 30 km Northeast of Tehran, was selected because of its geographical location beyond the Alborz mountain range which served to block the polluted air from entering the area (Figure 2).

STUDY POPULATION

The study population consisted of two hundred children from each site between the ages of 5 and 11 years. There were 107 females and 93 males in the urban and 101 females and 99 males in the rural subgroups. In the urban site, an area of approximately 2 miles x 2 miles was chosen on the basis of its proximity to major roadways. All houses located on streets adjoining the roadways were considered eligible. Each street was canvased by knocking on doors, and those which were inhabited and which responded were invited to participate in the study. With the exception of two households, who refused to participate, all other households that were approached consented.

Children from rural areas included Lavasan and smaller surrounding villages within an approximately fifteen mile radius. In Lavasan, children were

recruited by the door-to-door method described above. In the smaller villages, where possible, organized gatherings of children were arranged by the Department of Public Health in nearby health centers. The response rate for participation was greater than 99% in both areas.

RESPIRATORY HEALTH QUESTIONNAIRE

In both regions, parents or guardians were approached about the study and told its purpose. Having received written consent, a respiratory health questionnaire was administered to parents or guardians of subjects. This questionnaire, a modified version of the Recommended Respiratory Disease Questionnaire for Use with Adults and Children in Epidemiological Research[58] translated into Farsi, was used to obtain information on the child's respiratory illness history and respiratory symptoms, as well as potential confounding variables that may have influenced respiratory health such as home cooking and heating sources, smoking patterns within household, and parental education (sample questionnaire included in appendix).

ANTHROPOMETRIC MEASUREMENTS

Following completion of the questionnaire, the subject's erect standing height, without shoes, was measured using measuring tape to the nearest 0.25 inches. Next, the child's weight, without shoes, was measured to the nearest pound using a portable scale.

PULMONARY FUNCTION MEASUREMENTS

Two tests of pulmonary function were performed. First, the child's peak expiratory flow rate was measured by asking the child to perform forcible maximum exhalation from total lung capacity into a Personal Best peak flow meter. The readings from this instrument have been shown to have a linear relationship to the expected standard for both ATS waveform 24 as well as the Fleisch pneumotachometer, and thus to fulfill the National Asthma Education Program's technical standards.[59] Each subject was fitted with a nose clip, instructed to stand up and inhale as deeply as possible, place their lips firmly around the mouthpiece and blow out as fast and as hard as he or she could. The subject was told that their goal was to get the red indicator on the peak flow meter to the highest possible point on the scale. The test was repeated three times. The highest value was defined as the child's PEF.

The second pulmonary function test used a portable Breon Spirometer (Model 2400) to obtain a tracing of their forced expiration at total lung capacity. Each subject was fitted with a nose clamp and was instructed to inhale as deeply as possible, seal their lips tightly around the mouthpiece, exhale as forcefully as possible and maintain expiration until the pen on the spirometer reached the end of the tracing. Each subject attempted a trial run using only the mouthpiece unattached to the tube to acquaint him or her with

the procedure and to make sure that he or she could perform the task correctly. Evidence of acceptable performance included an unhesitating start, apparent maximal effort with smooth continuous exhalation, absence of cough, glottis closure or mouthpiece obstruction by tongue or teeth. Once the child felt comfortable, the mouthpiece was attached to the spirometer, and the child was given at least three test trials, or as many as needed to obtain two consistent readings. Each child's spirometric tracings were analyzed for FEV_1 and FVC. The largest acceptable FEV_1 and FVC volumes were recorded, even if the two values did not originate from the same curve.

AIR POLLUTION MEASUREMENTS

Portable air monitoring devices to measure NO_2, SO_2, and PM_{10} were used in both urban and rural areas. Palmes tubes were used to measure the amount of NO_2 and SO_2 in ambient air. For each day of pulmonary function testing, two Palmes tubes, one for NO_2 and one for SO_2, were placed outside the home environment of one of the subjects who was tested during that day. The tubes were exposed to ambient air by removing the protective cap and hanging them near subjects' home environments, either in their yard or outside their doors or windows. Devices were hung approximately six to nine feet above ground level to minimize tampering. Approximately two weeks later (number of exposure hours ranging from 285-438), the tubes were retrieved, capped, and stored in

an air-tight plastic bag at room temperature until analysis. Analysis of the Palmes tubes was performed by Jim Sullivan at Harvard University.

PM_{10} was measured with a MINIRAM (Miniature Real-time Aerosol Monitor) Model PDM-3, a light scattering airborne particulate monitor whose operating principle is based on the detection of scattered electromagnetic radiation in the near infrared. The scattering sensing parameters were designed for preferential response to particles whose diameter ranges between 0.1 and 10 microns. During operation, a liquid-crystal display indicated the aerosol concentration in units of $\mu g/m^3$ which was updated every 10 seconds. PM_{10} levels were measured in the mornings (and sometimes in the afternoons) on each day of testing. Obtaining afternoon PM_{10} measurements was temperature dependent. On afternoons where the temperature exceeded 100 °F, the equipment had a high rate of failure. Daily PM_{10} values were calculated by averaging the morning and afternoon levels as measured over a one to two minute period. If afternoon measurements were unobtainable, only the morning levels were used in calculating daily PM_{10} levels. The error rate for a 1 minute averaging is approximated at $0.02\ \mu g/m^3$. The monitor was placed in a plastic bag and calibrated with filtered air prior to each reading.

METEOROLOGY

Meteorological data on local temperature and barometric pressure were

collected for each day of testing using hand held portable monitoring devices. Temperature was measured with a mercury thermometer, placed in the shade, at the start and completion of every day of testing. The daily temperature was calculated as the average of the two readings. Barometric pressure was measured with an aneroid barometer at the start of each day of testing.

RESULTS

AIR QUALITY

A total of 17 NO_2 and 15 SO_2 Palmes tubes in the urban and 8 NO_2 and 6 SO_2 Palmes tubes in the rural areas were retrieved for analysis. The exposure time of each Palmes tube was factored into calculating the ppm concentration of air pollutants in the subjects' ambient environment. Five NO_2 and nine SO_2 monitors were lost to theft or tampering and were therefore not included in the analyses. Within the urban area, the mean concentration of NO_2 was 0.0247 ppm (46.44 $\mu g/m^3$), SO_2 0.0158 ppm (45.19 $\mu g/m^3$), and PM_{10} 99.99 $\mu g/m^3$. In contrast, the mean concentrations for the rural site were NO_2 of 0.00985 ppm (17.39 $\mu g/m^3$), SO_2 of 0.00651 ppm (18.62 $\mu g/m^3$) and PM_{10} of 0.01 $\mu g/m^3$ (Figure 3). The differences in concentrations for all three pollutants were significant at the 0.001 level (Table 1).

To assess the validity of the air pollution data, pollutant levels were

compared to those gathered during the same time period by the Iranian Department of Environmental Health (IDEH) in Tehran. For the months of June-July of 1994, the IDEH reports a mean NO_2 concentration of 0.052 ppm, SO_2 of 0.038 ppm and TSP of 159 $\mu g/m^3$ (no PM_{10} levels were measured). The IDEH levels of NO_2 and SO_2 are higher than those recorded by our portable monitoring devices (PMDs). Several factors could explain this discrepancy. The central IDEH collection site is located on a major thoroughfare in a non-residential area in mid-town Tehran, approximately 6 km north of the urban site. The proximity of the central monitoring station to mobile sources of air pollutants would allow for detection of more concentrated levels of such pollutants. In contrast, the PMDs in this study were placed within the yards and surrounding vicinity of the children's homes, further away from the direct influence of mobile sources (as there were no residential areas situated on the major thorough ways). The lower values measured by the PMDs may be more representative of the actual exposure to pollutants in the ambient air. Alternatively, the IDEH levels may be more accurate given the small sample size of the PMDs or may be discrepant based on differences in instrumentation.

In comparing the IDEH values to the WHO guidelines[8] and the National Ambient Air Quality Standards (NAAQS) for annual arithmetic means of these

air pollutants,[60] it is evident that the IDEH levels of SO_2 and TSP exceed both the WHO and NAAQS guidelines (Table 2). IDEH measured NO_2 levels border the NAAQS established standard of <0.053 ppm but fall well below the WHO guideline of <0.080 ppm. Although the PMD levels of SO_2 and NO_2 did not exceed the established guidelines, the PM_{10} did exceed the WHO standard of $<70\ \mu g/m^3$ as well as that of the NAAQS of $<50\ \mu g/m^3$.

LUNG FUNCTIONS

Using the meteorologic data collected for each day, the measured lung volumes were corrected to BTPS standards. The following formula was used to calculate corrected lung volumes:

$$\text{Corrected lung volumes} = \text{Uncorrected lung volumes} \times (P_a \times T_b)/(P_b \times T_a)$$

where:

P_a = [Barometric pressure (inches Hg) x 25.4 mm/inch] - water vapor pressure at ambient temperature

P_b = [Barometric pressure (inches Hg) x 25.4 mm/inch] - water vapor pressure at 37 degrees Celsius

T_a = Ambient temperature (degrees Celsius) + 273.18

$T_b = 37 + 273.18$

The BTPS corrected FEV_1s and FVCs were then compared to the predicted values. Predicted values were calculated for each child based on the

child's age, sex and height using a formula derived from studies of healthy American children.[61] Similarly, predicted values for PEF were calculated based on the child's height using established norms from studies of healthy British children.[62]

The mean percent predicted FEV_1 of children in the urban area was 89.0% (SD=23.7%) whereas that of the rural area was 99.0% (SD=18.9%). Similarly, the mean percent predicted FVC in the urban area was 89.7% (SD=22.9%) whereas the rural percent predicted FVC was 106.3% (SD=17%). For both FEV_1 and FVC, this difference was significant at the $p<0.001$ level as measured by Levine's Test. The mean percent predicted PEF of the urban area (82.4%, SD=13.5%) did not differ significantly from that of the rural area (81.8%, SD 16.9%--Table 3 and Figure 4).

To assess if other variables contributed to the lower lung function of the urban children, indoor air quality, socioeconomic status, and nutritional status were explored. With regard to indoor air quality, three potential sources of pollutants were examined: cooking sources, heating sources and tobacco smoke (Table 4). Cooking and heating sources were categorized based on their fume-generating capability. Cooking fuels such as fuel oil, kerosene and coal burners were categorized as fume-generating sources whereas central gas stoves were categorized as a non-fume generating source. Rural households used more

fume-generating cooking sources (17 rural vs. 2 urban, $p<0.001$). A similar trend held true for heating sources. Rural households used more fume generating heating sources such as petroleum and charcoal furnaces and kerosene burners as compared to urban homes which relied more heavily on central gas (171 rural vs. 2 urban, $p<0.001$). With regard to smoking patterns, more fathers smoked in the rural area ($p<0.016$). Maternal smoking was approximately equal in incidence in both areas (4 in rural, 3 in urban, $p<0.70$).

Socioeconomic status (SES) is considered a risk factor for respiratory disease.[63] The indices that were used to assess SES in this study were the size of the household, the number of rooms in the house, and the educational level of the parents. The number of rooms per household and the number of people in the household did not differ significantly between the rural and urban areas ($p<0.20$ and $p<0.40$ respectively). However, the mean number of years of education of the father (urban mean = 8.8 years, rural mean = 6.4 years) as well as the mother (urban mean = 6.9 years, rural mean = 5.2 years) were significantly greater in the urban area (Table 5).

The measures of nutritional status included children's height for age, weight for age, and body mass index (weight in grams/[height in cm]^2). The two populations did not differ significantly with respect to age ($p<0.12$),

weight ($p<0.07$), or body mass index ($p<0.53$). The urban children were slightly taller than rural children overall ($p<0.05$). The urban/rural comparison of these anthropomorphic variables is illustrated in table 6. The similarity in nutritional status is illustrated in figures 5 and 6 which show an urban-rural comparison of age vs. weight and age vs. height for both urban and rural children.

The respiratory symptoms that were investigated in the questionnaire were coughing, phlegm and wheezing. In addition, the incidence of physician-diagnosed asthma, bronchitis, pneumonia and sinusitis were assessed. A summary of the frequency of reported respiratory symptoms is presented in table 7. Although the rural and urban children did not differ in their episodes of coughing apart from colds, the rural children had more episodes of cough with colds ($p<0.025$). Rural children also had more phlegm with colds ($p<0.009$), and phlegm apart from colds ($p<0.042$) with cough or phlegm that lasted for more than one week ($p<0.001$). Rural children had a greater number of chest colds per year when compared to urban children ($p<0.028$) though chronic chest illnesses defined as those lasting 7 or more days did not differ in prevalence between the two groups. With regard to wheezing, rural children wheezed more while having a cold ($p<0.001$), apart from having a cold ($p<0.011$), had more episodes of wheezing leading to shortness of breath

($p<0.051$) and wheezed more during exercise ($p<0.014$). No children in the rural area were diagnosed with asthma, whereas three in the urban area carried the diagnosis ($p<0.082$). More rural children had pneumonia ($p<0.010$) and sinusitis ($p<0.030$) whereas more urban children had episodes of bronchitis ($p<0.008$). Thus, where differences in frequency of reported symptoms exist, rural children reported having more respiratory symptoms overall.

DISCUSSION

Tehran, the most industrialized urban center in Iran, harbors thirty-seven percent of the nation's industrial activity. Both light and heavy industries, such as oil refineries, cement plants, sulfuric acid plants, plaster works and foundries are contained within the city's boundaries.[4] Tehran's rapid population growth has lead to an increase in both mobile and stationary pollutant sources. These sources, lacking stringent emission standards, have resulted in poor ambient air quality within the city. The aim of this study was to determine how levels of these ambient air pollutants affected children's lung functions.

The results of this study indicate that spirometric lung function measurements of urban children were consistently lower than those of rural children. The average percent predicted FVC and FEV_1 in the urban area were

16.6% and 10.0% less than those of the rural area. This difference could not be explained by differences in anthropomorphic measurements of the children, in exposures to differing sources of indoor air quality such as cooking , heating, or paternal smoking, or by socio-economic factors. The decrements in lung function were, however, associated with differences in ambient levels of SO_2, NO_2, and PM_{10} amongst urban and rural areas.

Ambient air quality was measured using portable monitoring devices (PMDs). The PMD-measured levels of NO_2 and SO_2 were slightly less than half of the values measured by the Iranian Department of Health's (IDEH) central monitoring station for the same time period in central Tehran. This difference in levels is most likely attributable to the location on the monitoring stations. The IDEH monitoring station was located in a heavily trafficked thorough way in a non-residential area whereas the PMDs were placed in back yards of subjects which were not in as close a proximity to direct exposure from mobile sources. With regard to NO_2, the monthly mean as measured by IDEH was 0.052 ppm, barely under the NAAQS established guideline of 0.053 ppm. For SO_2, the IDEH measurement of the monthly mean exceeded both the NAAQS and WHO guidelines by 20% and 60% respectively. The IDEH monthly mean of total suspended particles exceeded the NAAQS and WHO by two-fold, whereas the PMD measured value for PM_{10} exceeded the NAAQS

by two fold and the WHO guideline by 43% (table 2).

These high levels of air pollutants are not unusual for Tehran. Data on TSP and SO_2 levels over the past decade, as measured by the IDEH, indicate that levels of these pollutants regularly exceeded the WHO and NAAQS guidelines by several fold (Table 8). The most significant air pollutant in Tehran that has consistently violated established air quality guidelines is suspended particulate matter. As outlined in the introduction, several studies have recently pointed to particulates as the main culprit for the morbidity and mortality associated with air pollution episodes,[50-57] as well as decrements in pulmonary function associated with air pollution.[47-49] Shamsi's study of children residing in Tehran[2] also implicated TSP levels as the strongest predictor of respiratory illness.

As table 8 shows, Tehran experiences the least amount of air pollution during the summer. This study was conducted during the relatively unpolluted time period of summer. Therefore, the documented decrements in lung function may be more reflective of cumulative exposures.

This study has several strengths. For one, it is, to date, the only published study of the effects of ambient air quality on children's lung function in Iran. Shamsi [2] studied three areas within the city of Tehran with differing levels of air pollutants and found a positive correlation between the

frequency of respiratory symptoms as reported by students in a respiratory questionnaire and the amount of TSP and SO_2 in the ambient air. However, Shamsi's study did not include any measure of pulmonary function. Despite these trends, few studies have examined the physiological effects of poor air quality on respiratory function in Tehran. Other strengths include significant air quality differences between the urban and rural sites, good exposure data, a well-selected control group, and an extensive search for possible confounding variables.

This study also has several weaknesses, one of which being that the mean percent predicted PEF did not differ significantly between the urban and rural groups (p=0.472). The similarity in PEFs may be due to the fact that the peak flow meter is a less precise instrument for measuring pulmonary function. Although for the purposes of this analysis, the highest value of three efforts was defined as the child's peak flow value, there was a wide degree of variability within subjects. In contrast, the lung volume measurements demonstrated far less within-subject variability. Another concern is that not all of the spirograms met the ATS criteria for reproducibility, indicating variable effort. Also, some of the total measured lung volumes were lower than expected for height and weight, thus indicating submaximal effort. However, because this was observed in both urban and rural spirograms with similar

frequency, there was no bias in urban-rural comparisons.

Another weakness in the data is that although rural children had better overall lung function, they reported having more respiratory symptoms. Several factors may explain this discrepancy. For one, rural children reported having a borderline significant higher incidence of allergies to pollen and dust (11 rural vs. 4 urban, $p = 0.065$). Therefore, the increase in respiratory symptoms among the rural population may be due to differential exposure to allergens that may provoke coughing, phlegm and wheezing but not necessarily lead to a decrement in pulmonary function. Lavasan is one of the prime fruit-producing areas of Iran. The fruit trees, which blossom on an annual basis, can serve as prime pollen producing sources. This is in sharp contrast to the urban area, where few green spaces exist.

Alternatively, the differing incidences of symptomatology between the rural and urban areas may reflect differences in indoor air quality. As stated earlier, rural children tended to live in homes with more fume generating heating and cooking sources. These sources may have emitted more NO_2 into the home, especially if they were unvented. As highlighted in the introduction, NO_2 has been shown in epidemiological and animal studies to compromise immune response leading to an increase in bacterial and viral infections. However, exposure to NO_2 has not been linked with decrements in

lung function. Therefore, high indoor exposures of NO_2 could explain the increase in respiratory symptoms in rural children, as it would render them more suspendible to pulmonary pathogens, without necessarily causing decreases in FEV_1 and FVC.

Another factor that could be postulated to explain this difference is varying incidences of upper respiratory tract infection. The rural area is situated above the Alborz mountain range, lending it to a colder climate. Also, the rural area has inferior quality of sanitation. Some of the smaller villages in the rural area lacked a clean water supply. The combination of colder climate and poor sanitation may have contributed to higher incidences of respiratory infection especially during the winter months. When parents were asked to report their child's symptoms, their answers reflected the child's symptoms throughout the duration of the year. Thus, an increased amount of respiratory symptoms may have reflected increased incidence of upper respiratory tract infection occurring during the winter months with little sequelae on lung function during the summer months.

The findings of lower FEV_1 and FVC in the more polluted urban environment are in agreement with the current literature. The association between decrements in pulmonary function and TSP/PM_{10} levels suggested in this study has also been documented in other international studies. Dassen et

al. [48] noted declines in FEV_1 and FVC in children in Ijmond, Netherlands with TSP levels in the range of 200-250 μg/m^3. He et al [64] studied the effects of pollution on children's pulmonary function in urban and suburban areas of Wuhan, China and noted that decrements in FEV_1 and FVC were associated with high annual mean levels of SO_2 (59 μg/m^3), NO_2 (47 μg/m^3) and TSP (251 μg/m^3). They found that the average FVC and FEV_1 in children in the suburban area was 6.7 and 3.8 percent lower, respectively, as compared to the suburban area. Further analysis indicated that the suburban-urban difference in both FVC and FEV_1 increased with increasing height, suggesting a failure on the part of the urban children to maintain lung function growth. They suggested that exposures in childhood may slow lung maturation and growth with volume related indices, such as FVC being more severely effected than flow-related indices, such as FEV_1.

Similarity, Xu et al [65] in their study of adult pulmonary function in relation to TSP and SO_2 levels, also proposed that FVC may be better indicator for assessing the effects of long-term cumulative exposure to air pollutants. In this study, comparing the spirometic lung functions of urban children to rural children reveals a similar trend-- a larger decrement of FVC (16.6%) than FEV_1 (10.0%). This is consistent with Xu et al's, and He et al's hypothesis [64,65] that changes in FVC may be more reflective of long-term,

cumulative exposures.

In summary, in an urban-rural comparison of lung function and symptoms in Tehran, higher pollutant levels in the urban area were associated with lower lung function among children ages 5-11. This difference was not explained by indoor air quality, environmental tobacco smoke, differences in socioeconomic status, or by nutritional status. We believe that further research is warranted since the pollutant levels and health effects measured are consistent with studies in other parts of the world [46, 64,66,67] and could indicate an important and potentially irreversible response to ambient pollutants.

TABLE 1: Urban-Rural comparison of ambient air quality as measured by portable monitoring devices for June-August, 1994

	URBAN		RURAL		URBAN vs. RURAL
Pollutants	**Mean**	**SD**	**Mean**	**SD**	**p values**
NO_2 (ppm)	0.0247	0.0108	0.0099	0.0048	0.001
SO_2 (ppm)	0.0158	0.0042	0.0065	0.0033	<0.001
PM_{10} ($\mu g/m^3$)	99.9	72.4	0.01	0.01	0.001

TABLE 2: Comparison of PMD[*] and IDEH[†] measurements of ambient air pollutant levels in Tehran for une-July of 1994 to NAAQS[‡] and WHO[¶] Guidelines for Annual Arithmetic Means

Pollutants	**PMD**	**IDEH**	**NAAQS**	**WHO**
	One Month Mean	One Month Mean	Annual Arithmetic Mean	Annual Arithmetic Mean
NO_2 (ppm)	0.025	0.052	<0.053	<0.080[‖]
SO_2 (ppm)	0.016	0.038	<0.030	<0.015-0.023
PM_{10} ($\mu g/m^3$)●	100	not measured	<50	<70
TSP ($\mu g/m^3$)■	not measured	159	<75	<60-90

Portable Monitoring Devices

Iranian Department of International Health

U.S. National Ambient Air Quality Standards

World Health Organization

This value is the mean 24 hour guideline for NO_2. WHO has not established a guideline for annual arithmetic mean for NO_2.

● Particulate Matter less than or equal to 10 microns in diameter

■ Total Suspended Particulates

TABLE 3: BTPS corrected pulmonary function tests as a percent of predicted for age, height and sex

	URBAN		RURAL		URBAN vs. RURAL
Pulmonary Function Parameters	**Mean**	**SD**	**Mean**	**SD**	**p values**
FEV_1	89.0%	23.7%	99.0%	18.9%	<0.001
FVC	89.7%	22.9%	106.3%	17.3%	<0.001
PEF	82.4%	13.5%	81.8%	16.9%	0.472

TABLE 4: Urban-Rural Comparison of Home Environmental Exposure

Source	**Urban**	**Rural**	**Urban vs. Rural p value**
Fume generating cooking sources[1] (Number of households)	2	17	<0.001
Fume generating heating sources[2] (Number of households)	2	171	<0.001
Smoking (paternal)	72	94	0.015
Smoking (maternal)	3	4	0.698
Mean Number of cigarettes/day smoked in household	5.54	8.02	0.021

[1] Includes fuel oil, kerosene, and coal

[2] Includes petroleum furnace, charcoal furnace and kerosene burners.

TABLE 5: Urban-Rural Comparison of Socio-Economic Status (SES)

SES Measures	Urban	Rural	Urban vs. Rural p value
Rooms/household	2.74	2.66	0.467
People/household	5.60	5.76	0.173
Paternal education (yrs)	8.84	6.36	<0.001
Maternal education (yrs)	6.93	5.19	<0.001

TABLE 6: Urban vs. Rural Comparison of Anthropomorphic Data

	URBAN		RURAL		URBAN vs. RURAL
Anthropometric Parameters	**Mean**	**SD**	**Mean**	**SD**	**p values**
Age (years)	8.012	1.154	7.824	1.308	0.115
Height (inches)	48.874	3.359	48.217	3.288	0.049
Weight (lbs)	49.975	9.592	48.295	9.175	0.074
BMI (wt gm/[ht cm]^2)	1.461	0.171	1.451	0.152	0.534

TABLE 7: Urban-Rural Comparison of Respiratory Symptoms

	Number of Children with Respiratory Symptoms		
Symptom	**Urban**	**Rural**	**Urban vs. Rural p value**
Cough with cold	175	188	0.025
Cough apart from cold	15	12	0.550
Phlegm with cold	82	108	0.009
Phlegm apart from cold	4	12	0.041
Cough & phlegm for 1+ wk	20	50	<0.001
Wheeze with cold	37	66	<0.001
Wheeze apart from cold	1	9	0.010
Wheeze causing SOB	9	19	0.050
Wheeze during exercise	5	16	0.014
Asthma	3	0	0.082
Bronchitis	7	0	0.009
Pneumonia	11	26	0.010
Sinusitis	3	11	0.030

TABLE 8: IDEH mean monthly levels of TSP and SO_2 averaged from 1980 - 1989

MONTH	TSP ($\mu g/m^3$)	SO_2 (ppm)
January	294	0.179
February	302	0.165
March	262	0.106
April	242	0.075
May	242	0.077
June	246	0.077
July	271	0.088
August	280	0.080
September	293	0.094
October	304	0.081
November	291	0.106
December	274	0.159

FIGURE 1

Map of Iran

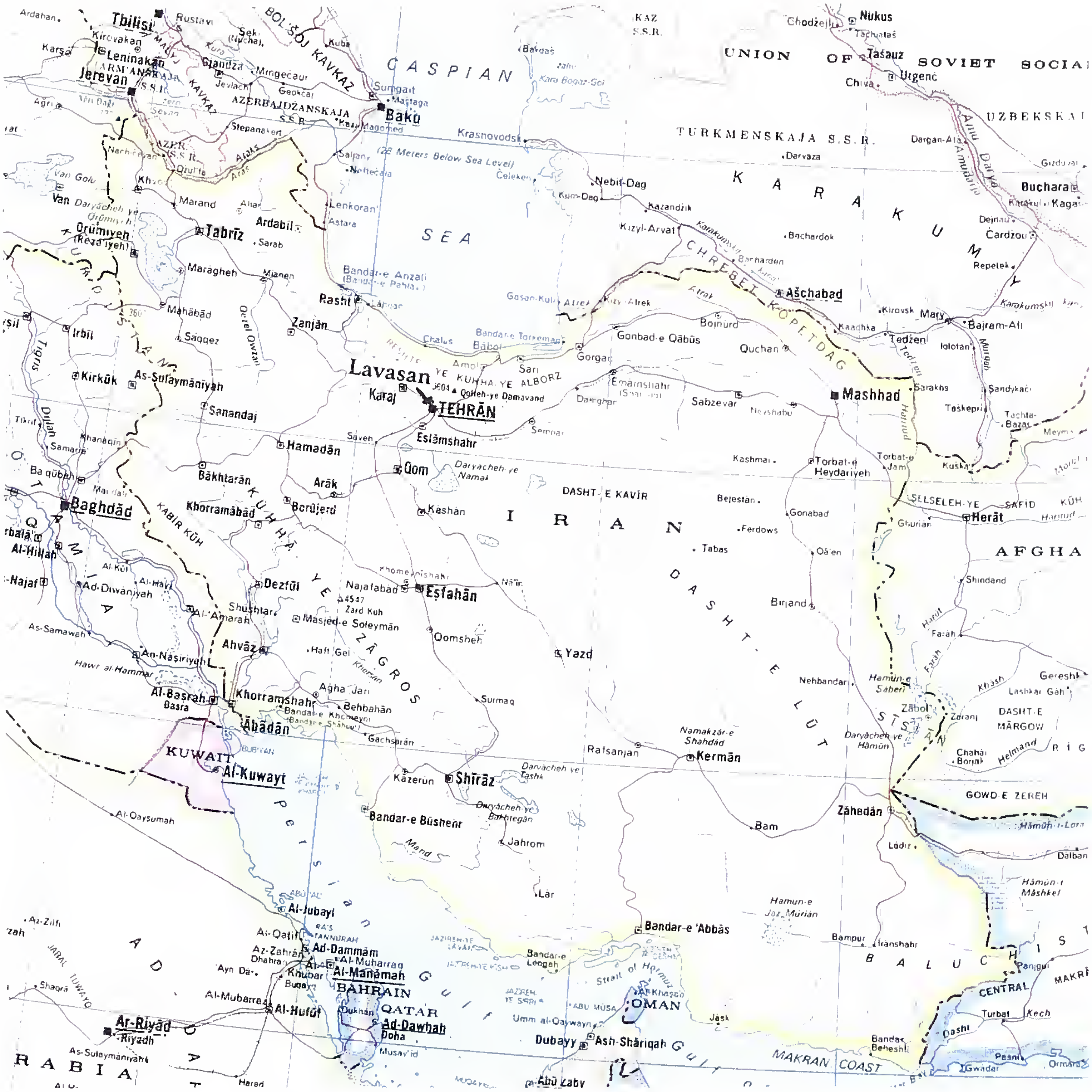


FIGURE 2

Map of Tehran ("urban") and Lavasan ("rual")

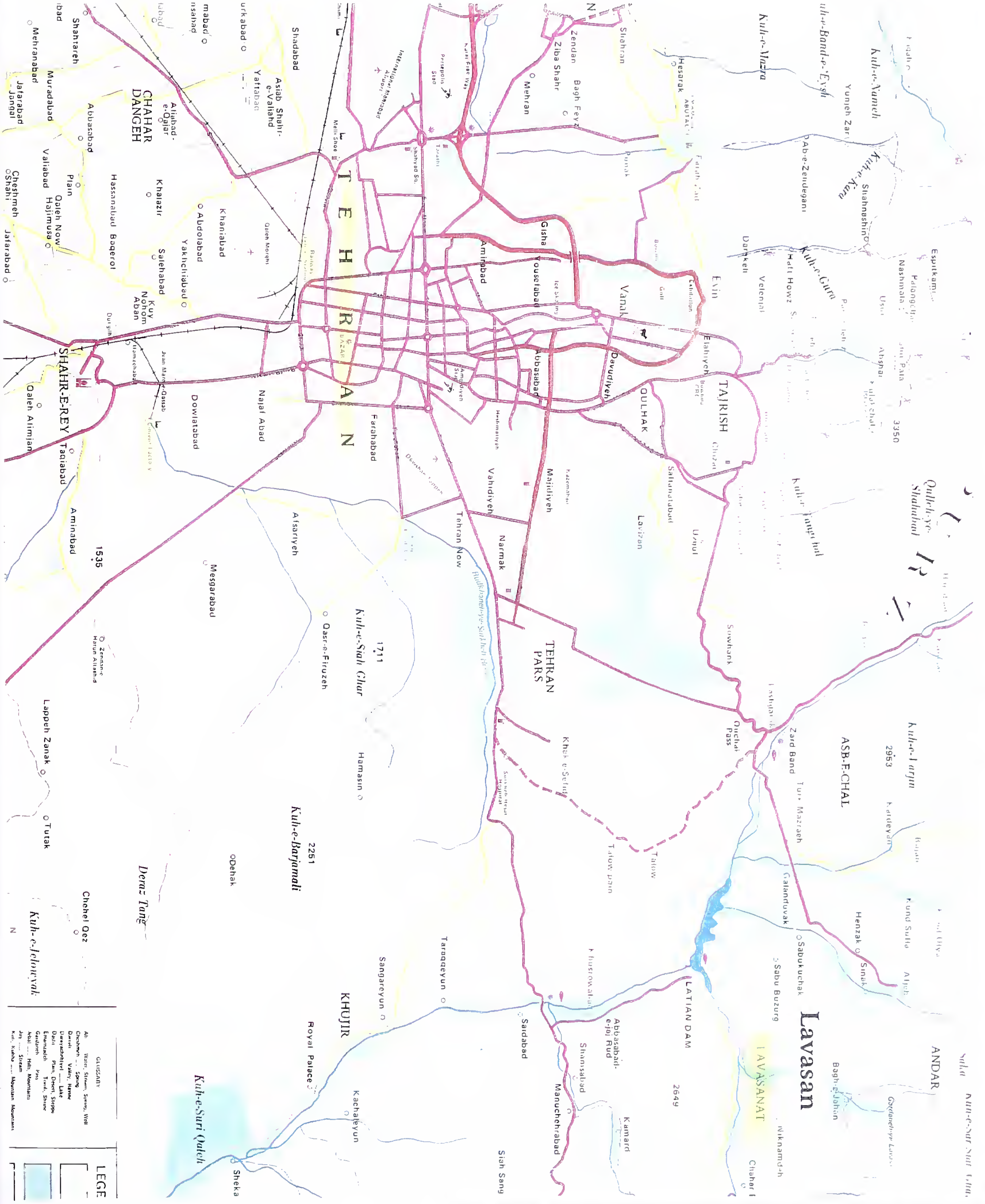
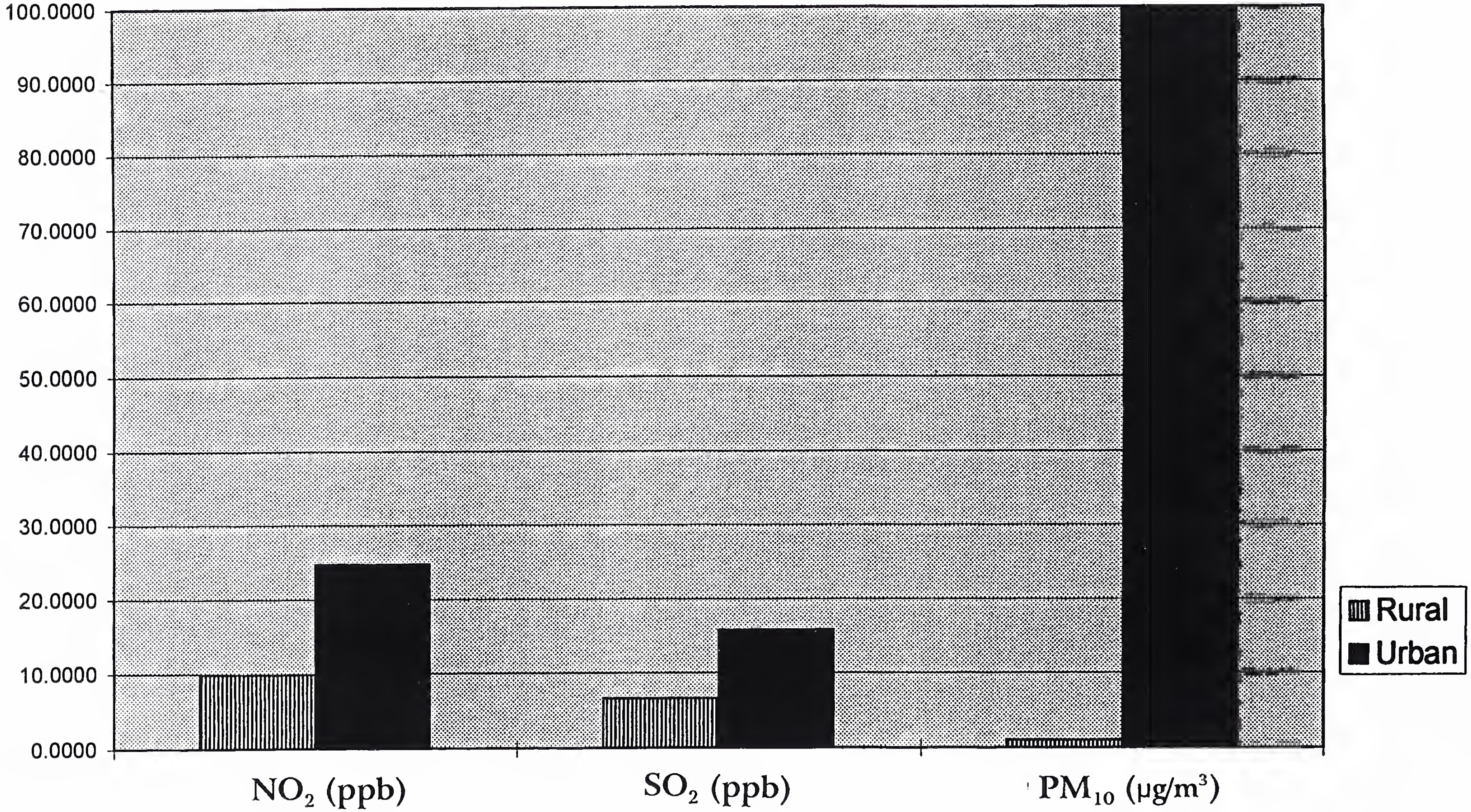


FIGURE 3

Urban-Rural Comparison of SO_2*, NO_2* and PM_{10} Levels as Measured by Portable Monitoring Devices (PMDs)



*: SO_2 and NO_2 levels are shown in ppb for ease of display. To convert values to ppm, multiply by 10^{-3}.

FIGURE 4

Urban-Rural Comparison of Percent Predicted Pulmonary Function Tests

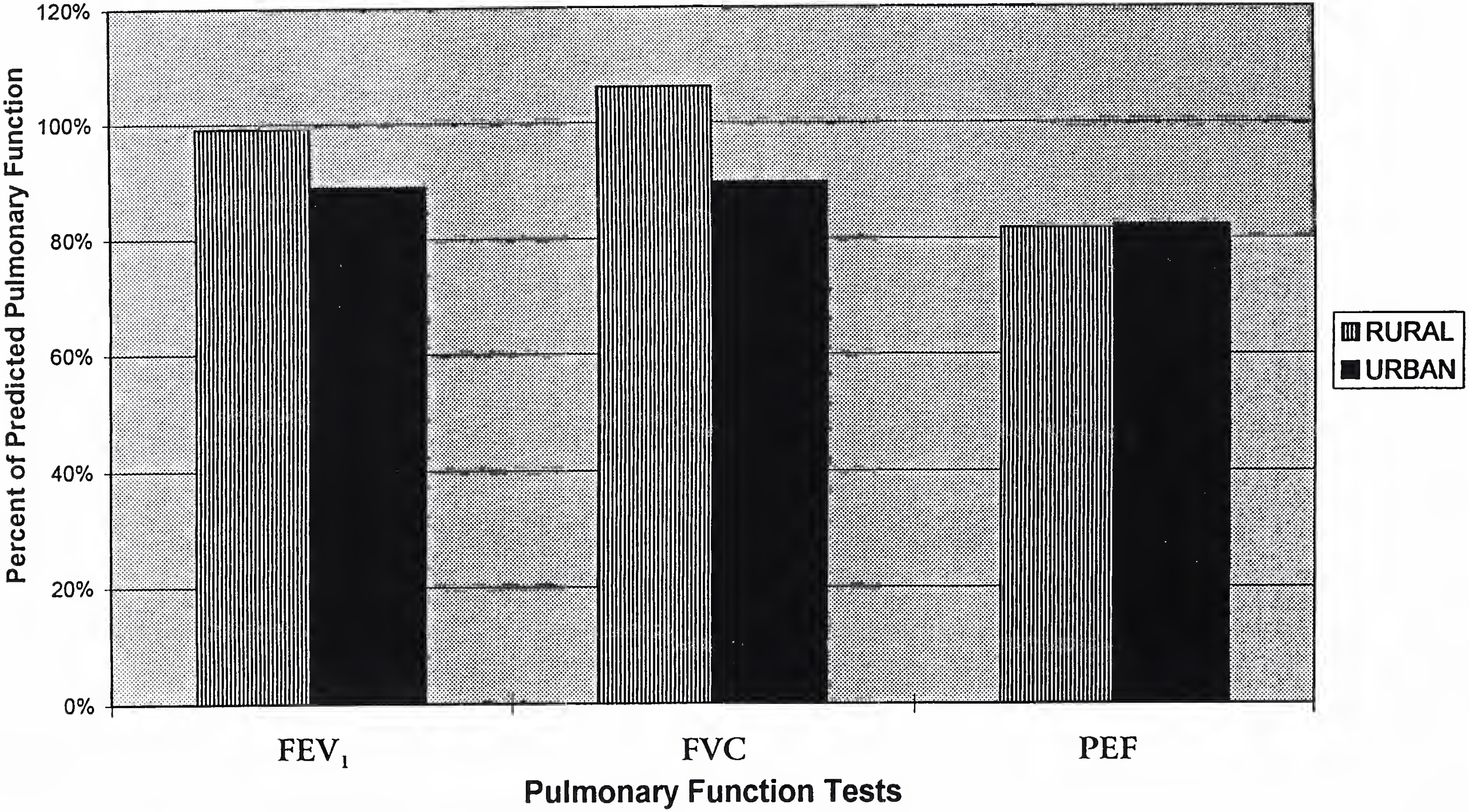


FIGURE 5

Age vs. Weight for Urban and Rural Subjects

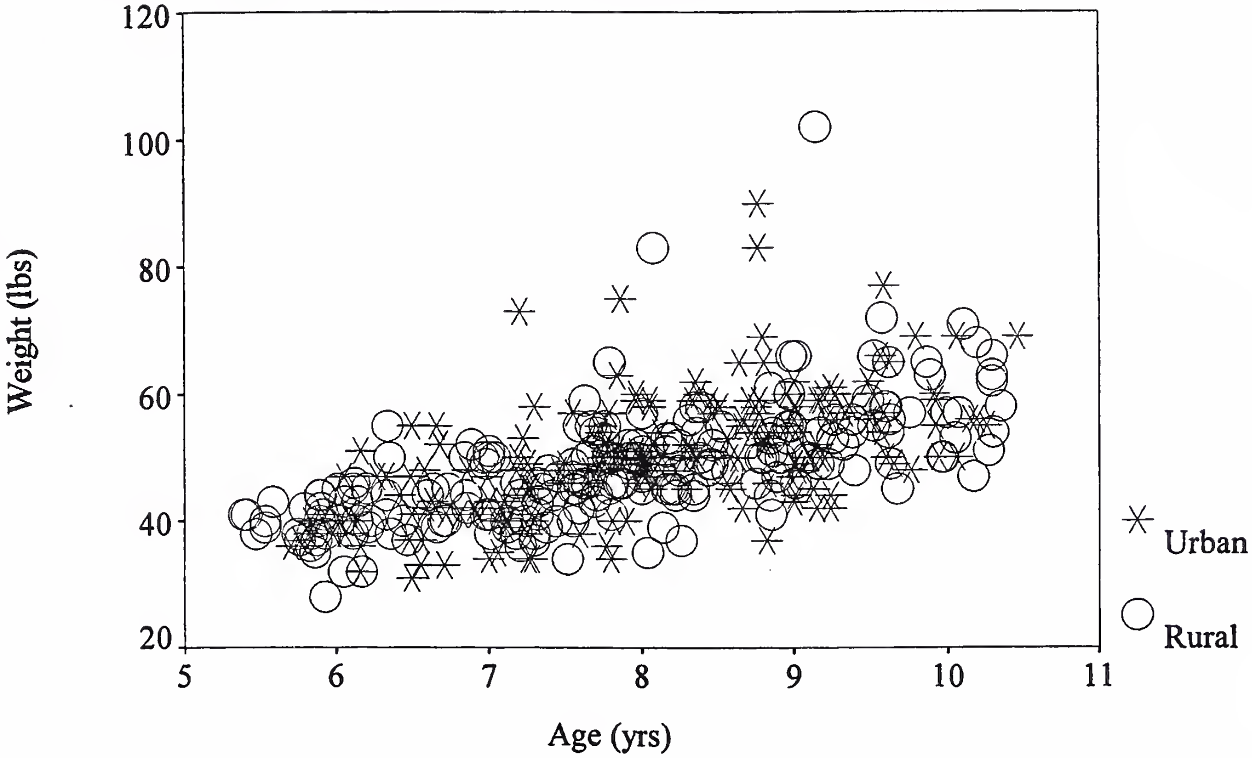
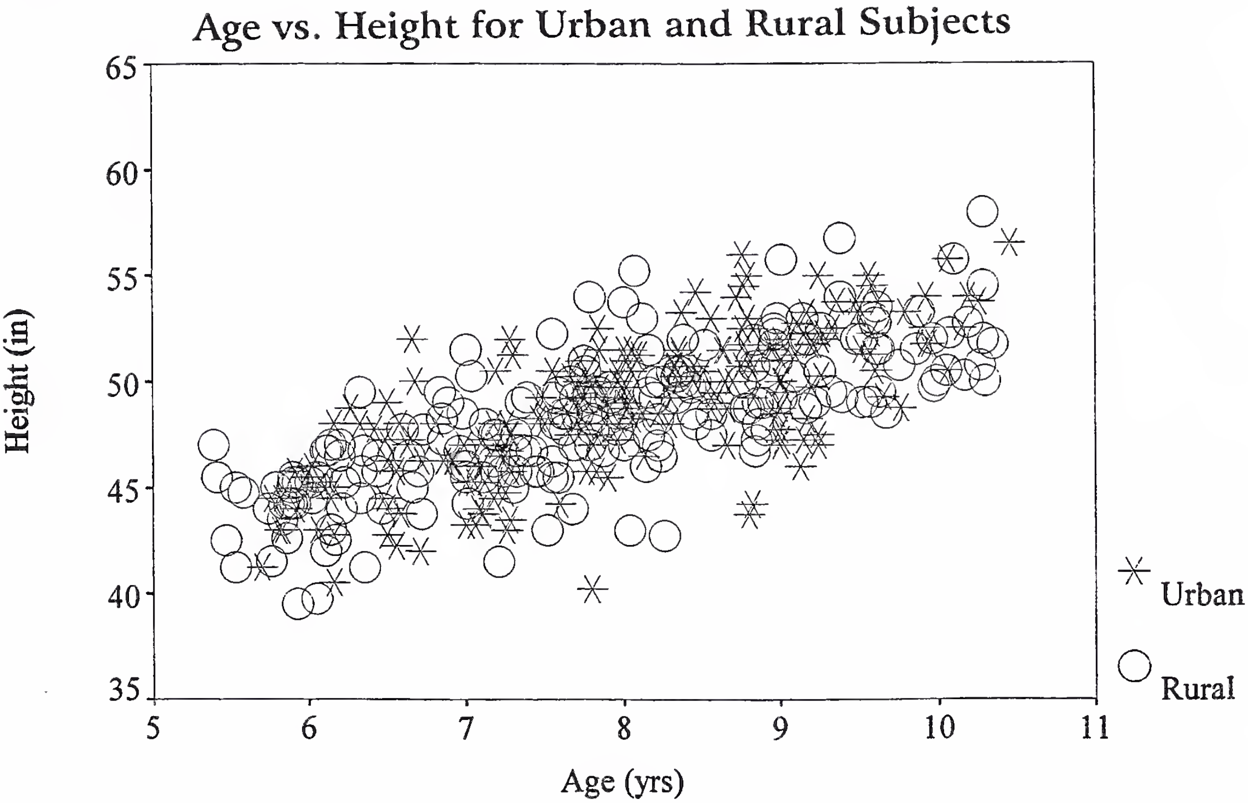


FIGURE 6



Age vs. Height for Urban and Rural Subjects

APPENDIX

Respiratory Health Questionnaire

1. ID ___________ 2. Date_____________ 3. Sex_________ 4. Location_______________________
5. Relation of person completing questionnaire to child _______________________________
6. Date of child's birth:____
7. Where was this child's mother living when this child was born?____________________
8. Please list all places where s/he lived for 6 months or longer, from birth to present:___________

____

9. Does s/he attend school?_________if so, what grade in s/he in? ____________________
10. What is the age of the youngest child living in this child's home?________________
11 A. How many people share his/her bedroom?___________________________________
   B. Does this child have his/her own bed? ______________________________________
   C. Do any of the people that share his/her room smoke? ________________________
12. How many rooms are in your house (not incl. bathrooms & kitchens)? ______________
13. How many people live in your home?_______________________________________
14 How is your home heated? ____
15. What fuel is used most for cooking in your home?____________________________
16. How is your home cooled?____
17. A. Do you have any pets?_______ If so, what kind?____________________________
   B. Do the pets reside mostly indoor or outdoor?_______________________________

COUGH

18. A. Does s/he usually have a cough with colds?_________________________________
   B. Does s/he usually have a cough apart from colds?____________________________
      IF YES (to part B):
      C. Does s/he cough on most days (4+ days/week) for as much as 3 months/year?_________
      D. For how many years has s/he had this cough?______________________________

PHLEGM

19. A. Does s/he usually bring up phlegm with colds?______________________________
   B. Does s/he usually bring up phlegm apart from colds?__________________________
      IF YES (to part B):
      C. Does s/he bring up phlegm, sputum, or mucus from his/her chest on most days
         (4+ days/week) for as much as 3 months per year?______________________________
      D. For how many years has s/he raised phlegm, sputum, or mucus from his/her chest?_____
20 A Does this child get attacks of cough, or phlegm lasting for 1 week or more each year?________
      IF YES:
      B. For how many years?____
      C. On average, how many chest colds per year does s/he get?__________________

WHEEZING

21. A. Does this child's chest ever sound wheezy or whistling when s/he has a cold?___________
   B. Does this child's chest ever sound wheezy or whistling apart from colds?___________
   C. Does this child's chest sound wheezy or whistling most days or nights?___________
      IF YES (to parts B or C):
      D. For how many years____
22. A. Has this child ever had an attack of wheezing that has caused him/her to be short of
      breath?____
      IF YES:
      B. Has s/he had 2 or more such episodes?_____________________________________
      C. Has s/he ever required medicine or treatment for the(se) attack(s)?___________
      D. How old was this child when s/he had his/her first such attack?_____________
      E. Is his/her breathing completely normal between attacks?_____________________

23. Does this child ever get attacks of wheezing after s/he has been playing hard or exercising?____

CHEST ILLNESS

24.A During the past 3 years. has this child had any chest illness that kept him/her from his/her usual activities for as much as 3 days?______________________________

IF YES:

A. Did s/he bring up more phlegm or seem more congested than usual with any of these illnesses?______________________________

B. How many illnesses like this has s/he had in the past 3 years?______________

C. How many of these illnesses have lasted for as long as 7 days?______________

25. Was s/he ever hospitalized for a severe chest illness/chest cold before the age of 2 years?____

26. Did this child have any other chest illness or chest cold before the age of 2 years?__________

OTHER ILLNESSES

27. Has this child had any of the following diseases?

A. Measles_______ B. Sinus Trouble________ C. Bronchitis ________

D. Croup_________ E. Whooping Cough_____ F. Pneumonia_______

28 A. Has this child had any ear infections between 0-2 years of age?______________

B. Has this child had any ear infections between 2-5 years of age?______________

C. Has this child had any ear infections over age 5?____________________

29. Did this child require tubes to be placed in his/her ears to drain them?______________

30. Did this child ever have an operation on his/her tonsils?____________________

31 A. Has a doctor ever said that this child had asthma?____________________

IF YES:

B. At what age did the asthma begin?____________________

C. Does s/he still have asthma?____________________

IF YES (to part C):

D. Is s/he currently taking any medication?____________________

IF NO (to part C):

E. When did it his/her asthma stop?____________________

32. Has this child ever had an operation on his/her chest?_______If so, specify______________

33. Does this child have heart disease?_________If so, specify______________________

34. When s/he was born, was s/he kept in the hospital after the mother went home?__________

if so, specify reason______________________________

ALLERGY

35. Does this child have an allergic reaction to food or medicine?____________________

36. Does this child have an allergic reaction to pollen or dust?____________________

37. Does this child have an allergic skin reaction to detergents or other chemicals?__________

38. Did this child ever receive allergy shots?______________________________

FAMILY HISTORY

MALE PARENT

39. Is he the natural father?______ If no, specify the relationship:____________________

40. What is the highest grade of school he completed?____________________

41. What is his present job?______________________________

42. A. Does he smoke regularly (at least 1 cigarrette per day)?____________________

IF YES:

B. With what frequency?______________________________

43. A. Does he smoke any other type of tobacco, ie: cigars, pipe, etc.?________________

IF YES:

B. Specify type and frequency of usage______________________________

44. A. Has he ever smoked regularly while living at home with this child?______________

IF YES:
B. With what frequency?____

45. Has a doctor ever said he had:
A. Bronchitis______________ B. Emphysema______________ C. Asthma____________
D. Any respiratory condition (specify)__________________________________

FEMALE PARENT

46. Is she the natural mother?______ If no, specify the relationship:________________________
47. What is the highest grade of school she completed?__________________________________
48. What is her present job?____
49. A. Does she smoke regularly (at least 1 cigarrette per day)?______________________________
IF YES:
B. With what frequency?____
50. A. Does she smoke any other type of tobacco, ie: cigars, pipe, etc.?____________________
IF YES:
B. Specify type and frequency of usage____
51. A. Has she ever smoked regularly while living at home with this child?____________________
IF YES:
B. With what frequency?____
52. Has a doctor ever said she had:
A. Bronchitis______________ B. Emphysema______________ C. Asthma____________
D. Any respiratory condition (specify)__________________________________

OTHER HOUSEHOLD MEMBERS

53. A. Are there any other members of the household who currently smoke regularly?__________
IF YES:
B. Specify relation____
C. With what frequency?____

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